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Coppedge et al.

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(54) **MULTIPLE GAS GENERATOR DRIVEN PRESSURE SUPPLY**

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F15B 11/08 (2006.01)
E21B 33/064 (2006.01)

(52) **U.S. Cl.**
CPC ***F15B 1/08*** (2013.01); ***E21B 33/064*** (2013.01); ***F15B 11/08*** (2013.01); *F15B 2201/00* (2013.01)

(58) **Field of Classification Search**
CPC F15B 1/08; F15B 33/064; F15B 11/08; F15B 2201/00
USPC 60/634
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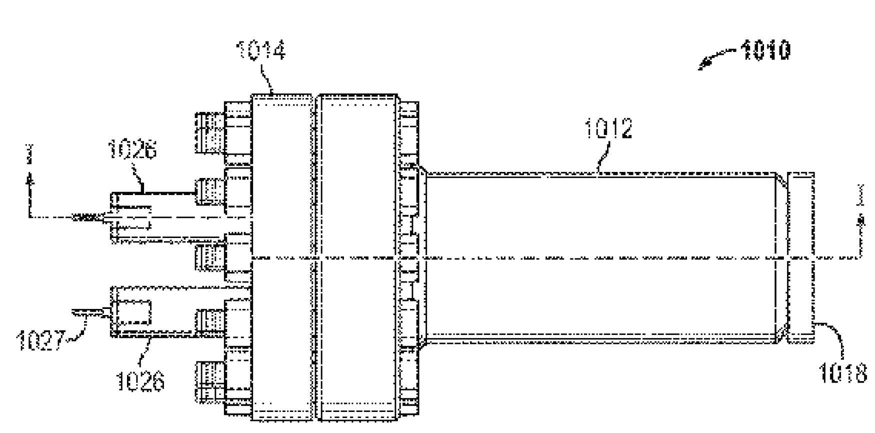
(74) *Attorney, Agent, or Firm* — Winstead PC

(57) **ABSTRACT**

A pressure supply device in accordance to one or more aspects includes an elongated body having an internal bore extending from a power end to a discharge end having a discharge port, two or more gas generators connected to the power end and a hydraulic fluid disposed in the bore between a piston and the discharge end. The ignition of one of the gas generators drives the piston to exhaust a partial volume of the hydraulic fluid that is less than the total operational volume of the hydraulic fluid under pressure to operate at a connected device.

20 Claims, 13 Drawing Sheets



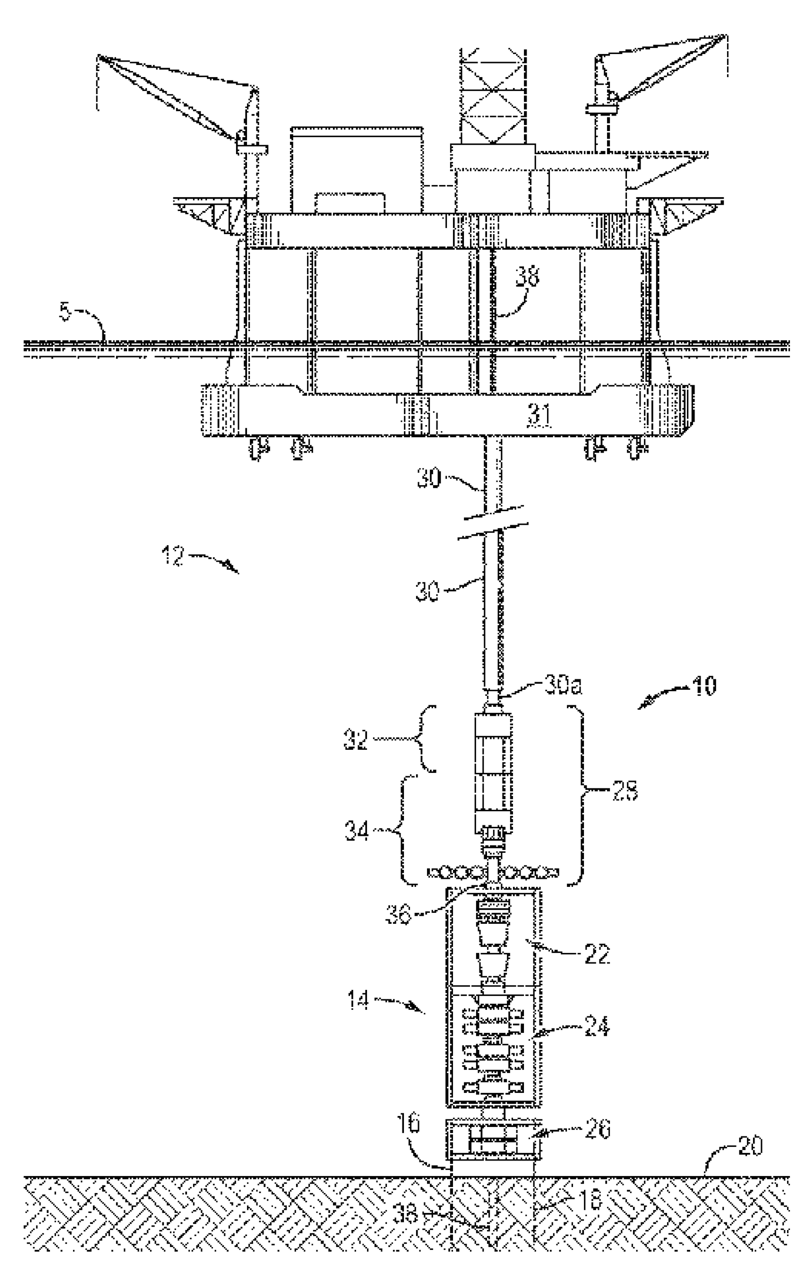


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FIG. 1

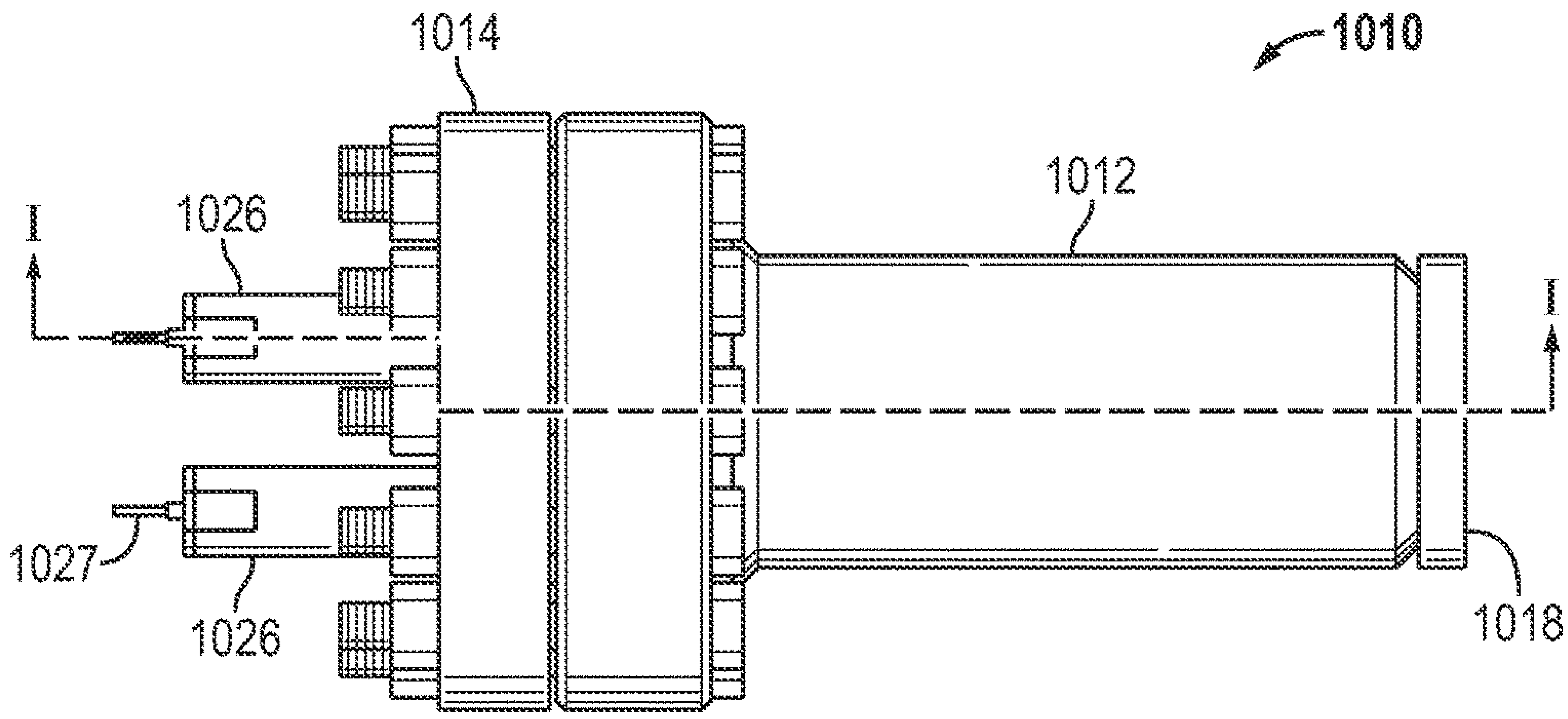
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FIG. 2

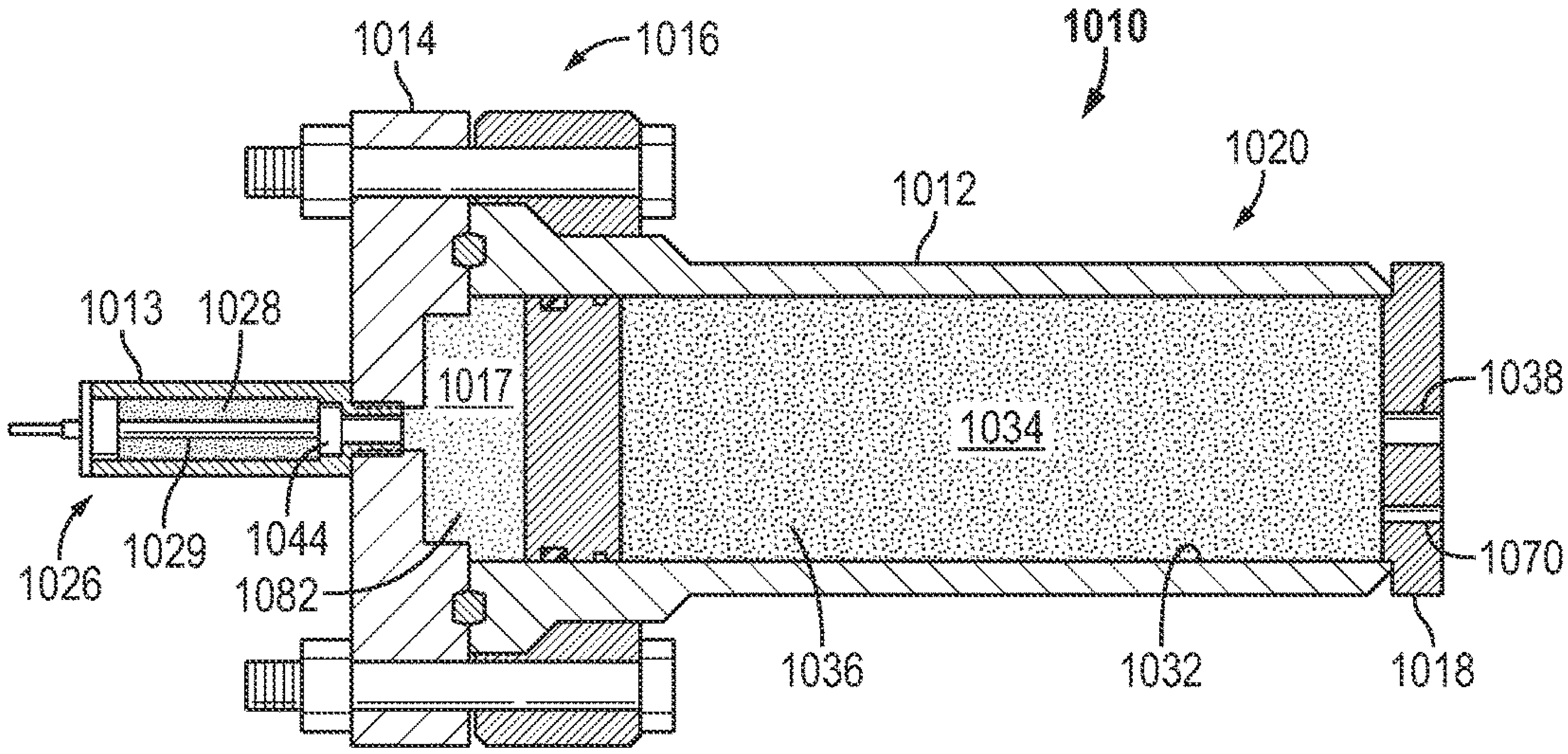
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FIG. 3

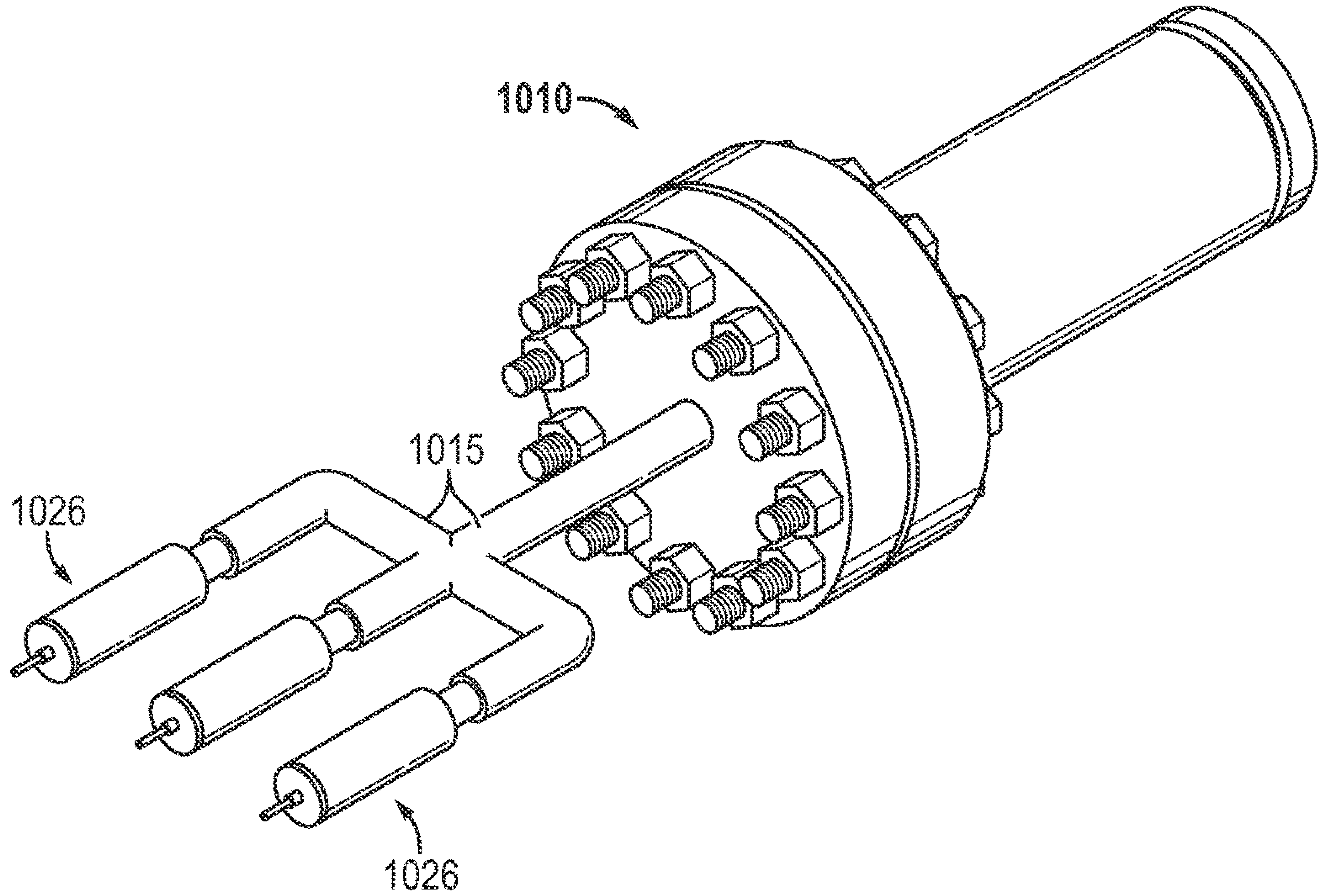
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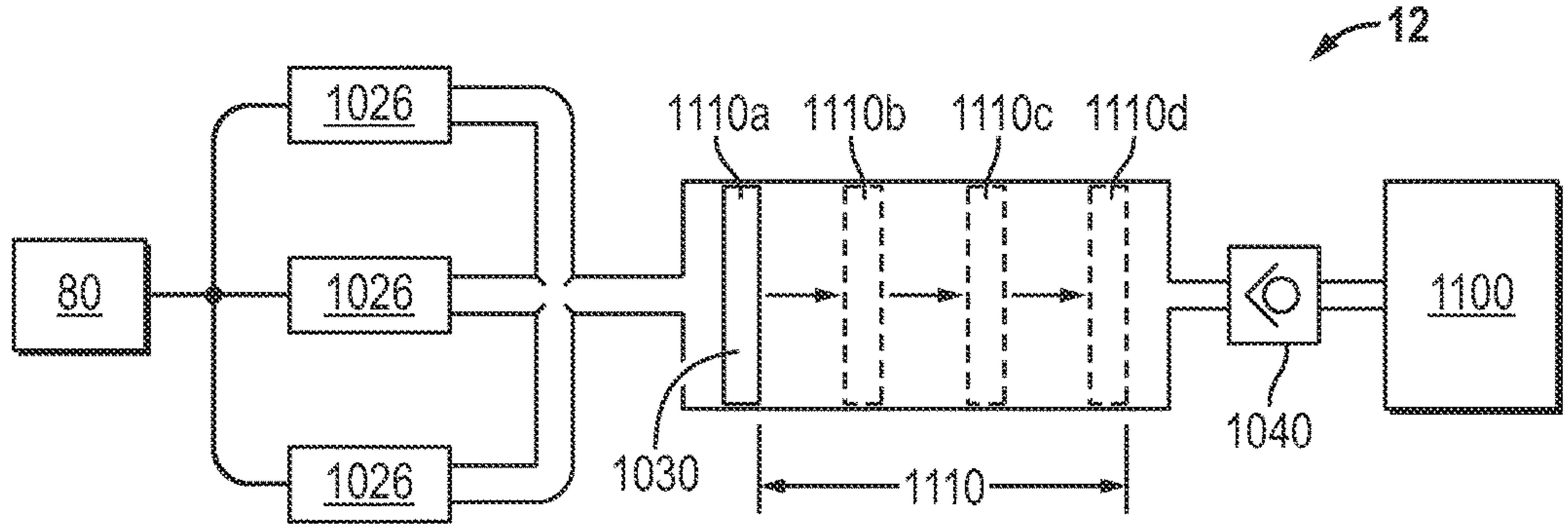
FIG. 4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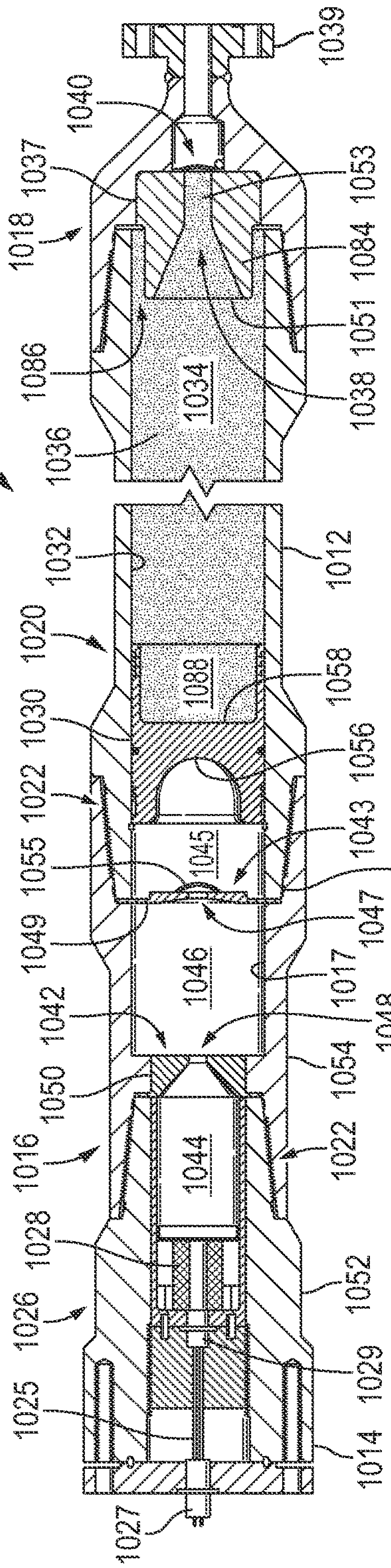
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FIG. 5

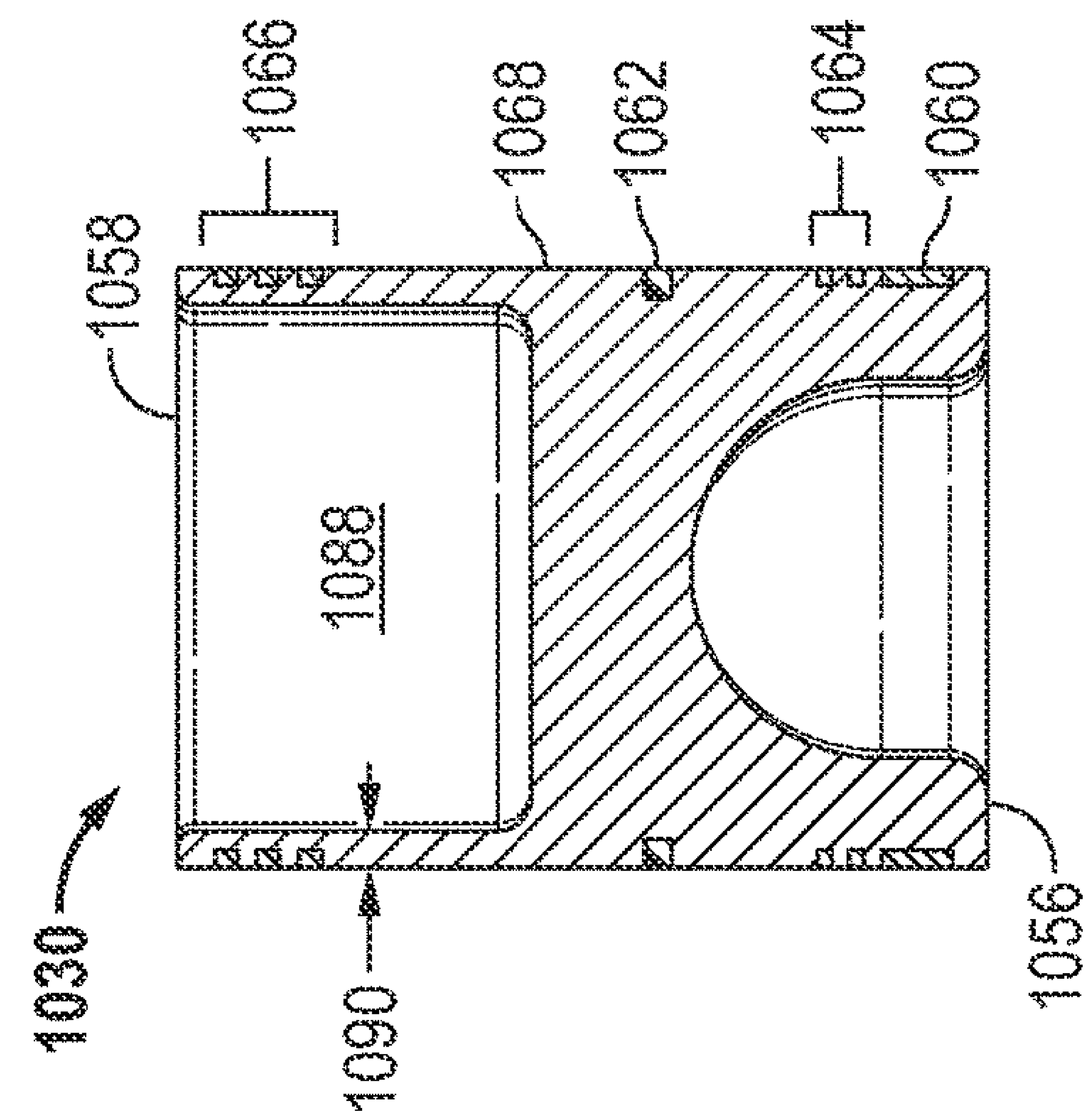
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FIG. 6

FIG. 7

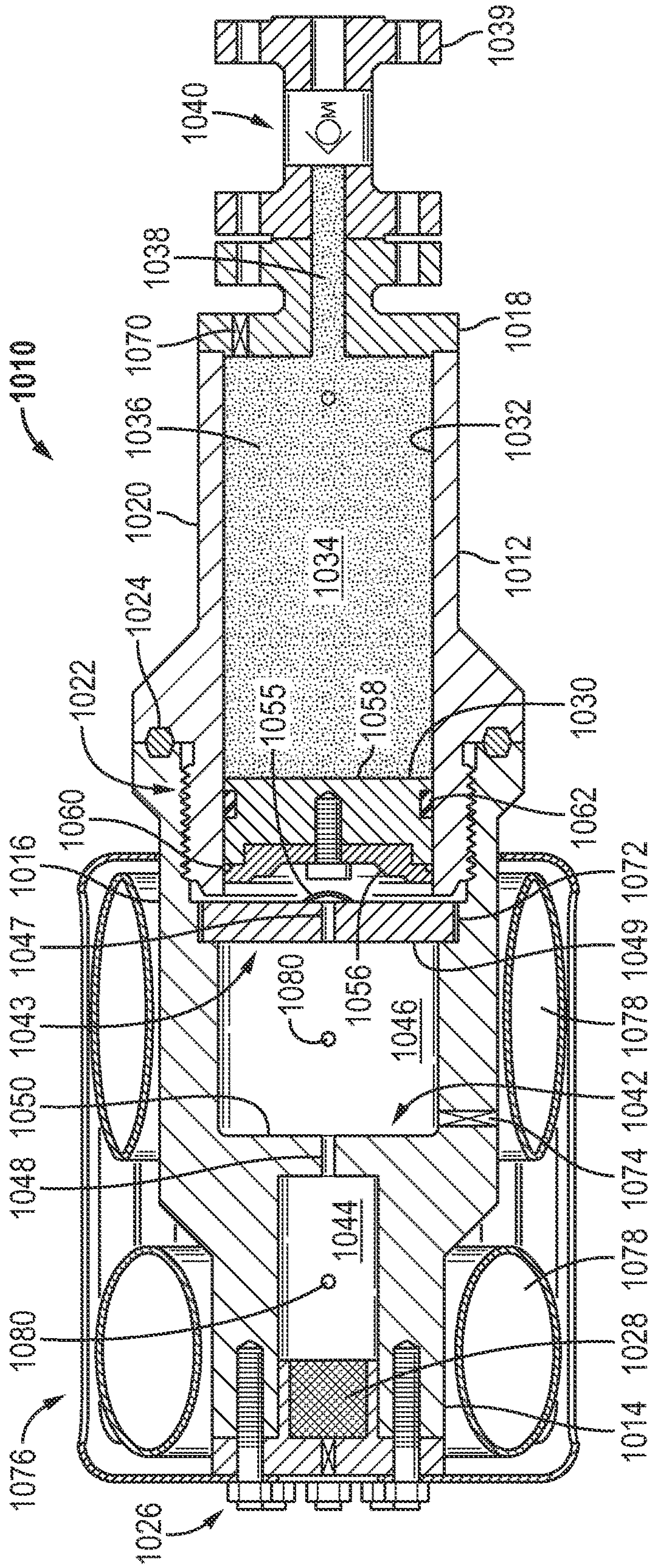
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FIG. 8

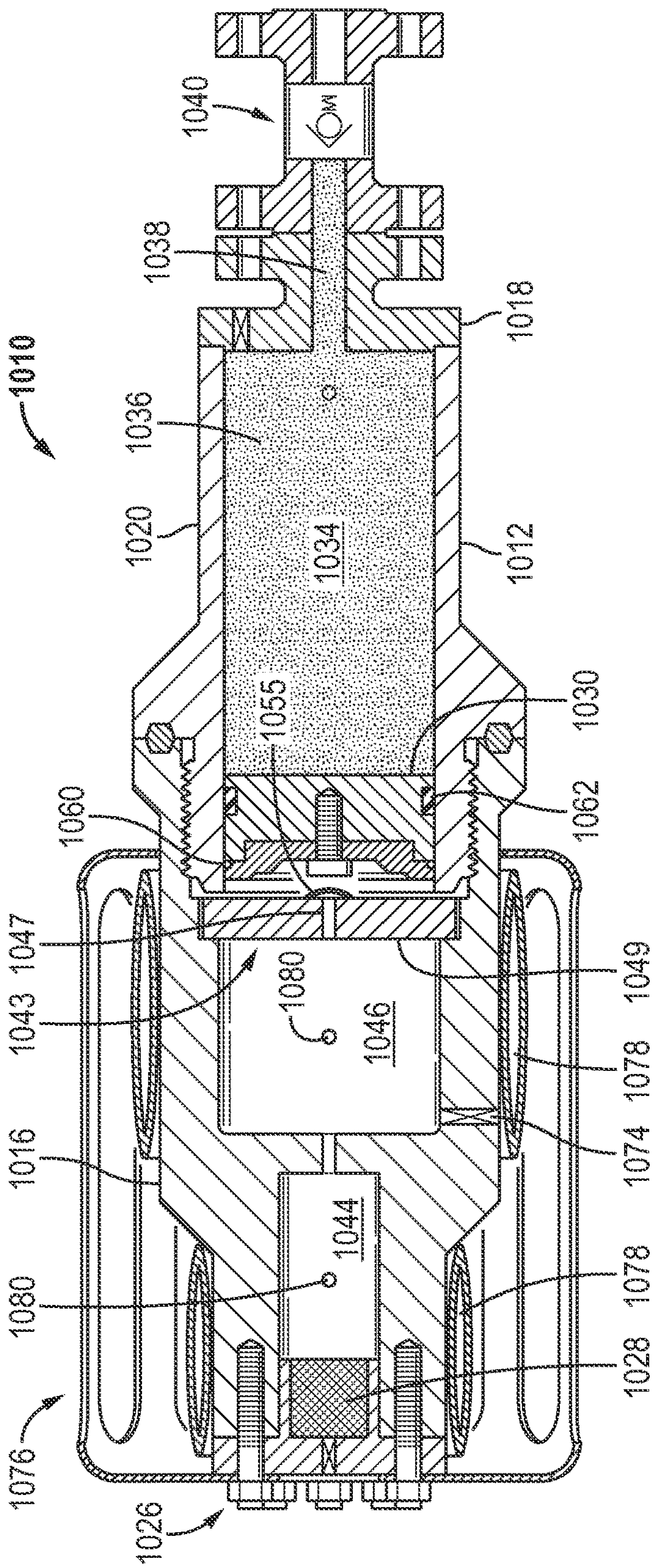

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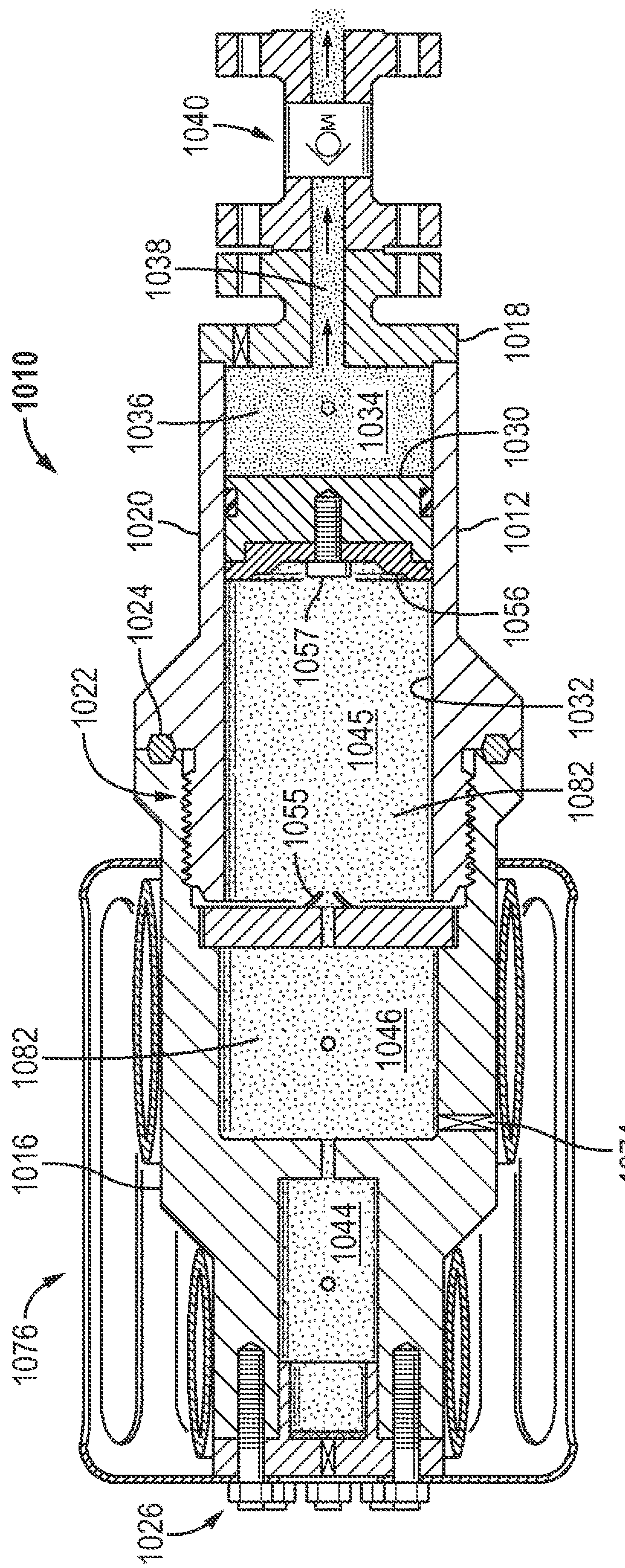
FIG. 9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1016
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FIG. 10

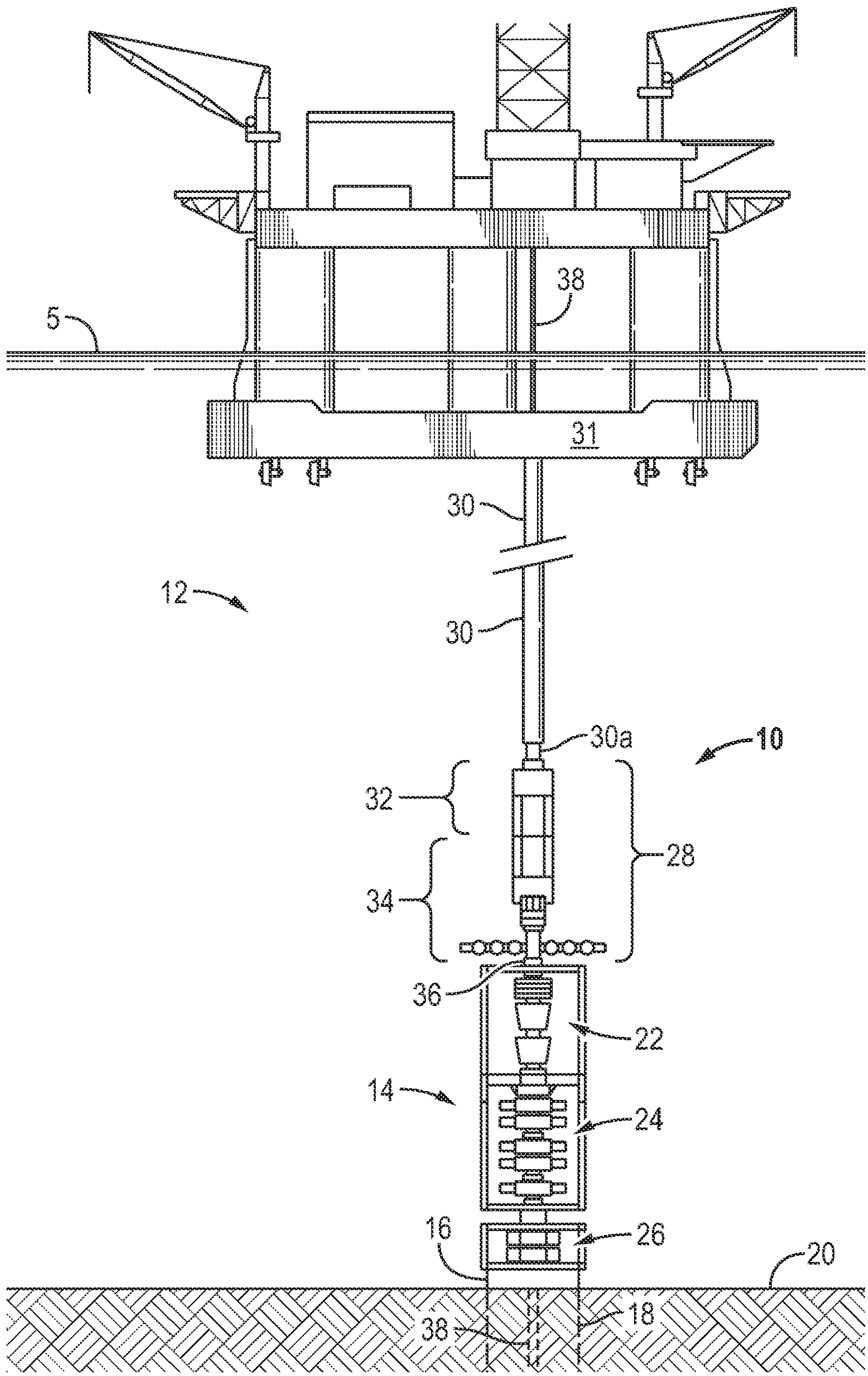

FIG. 11

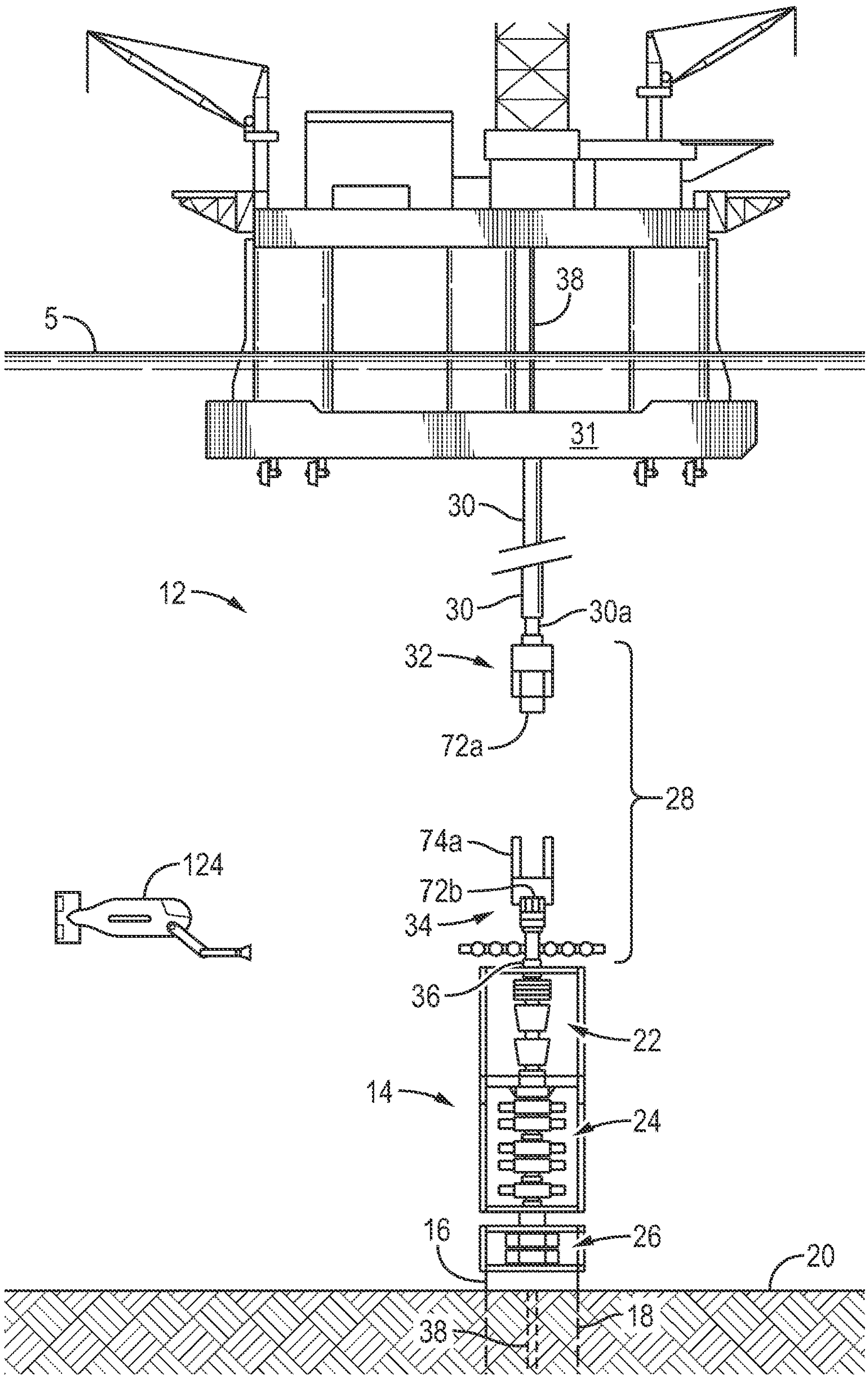
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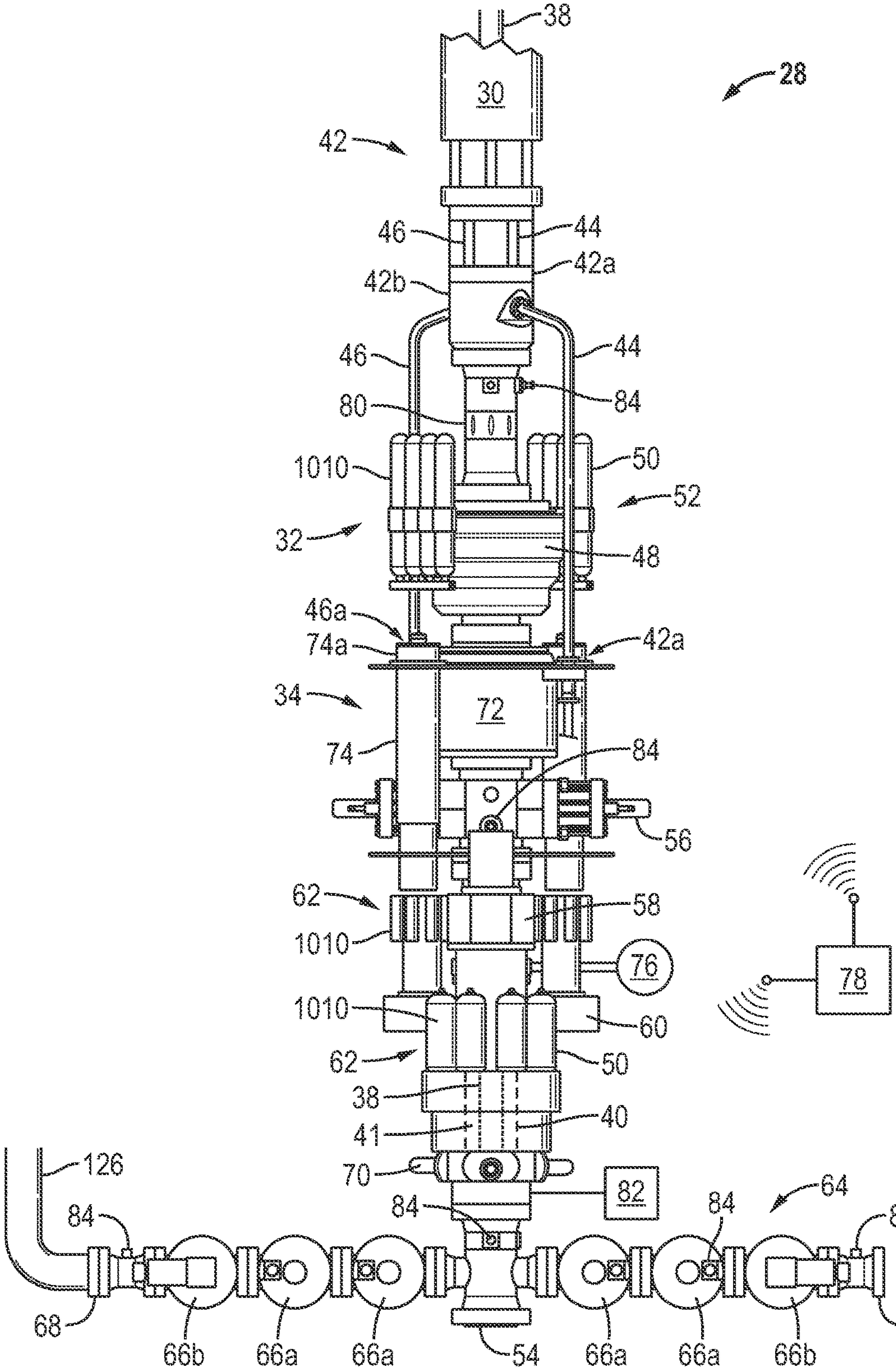
FIG. 12



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66b
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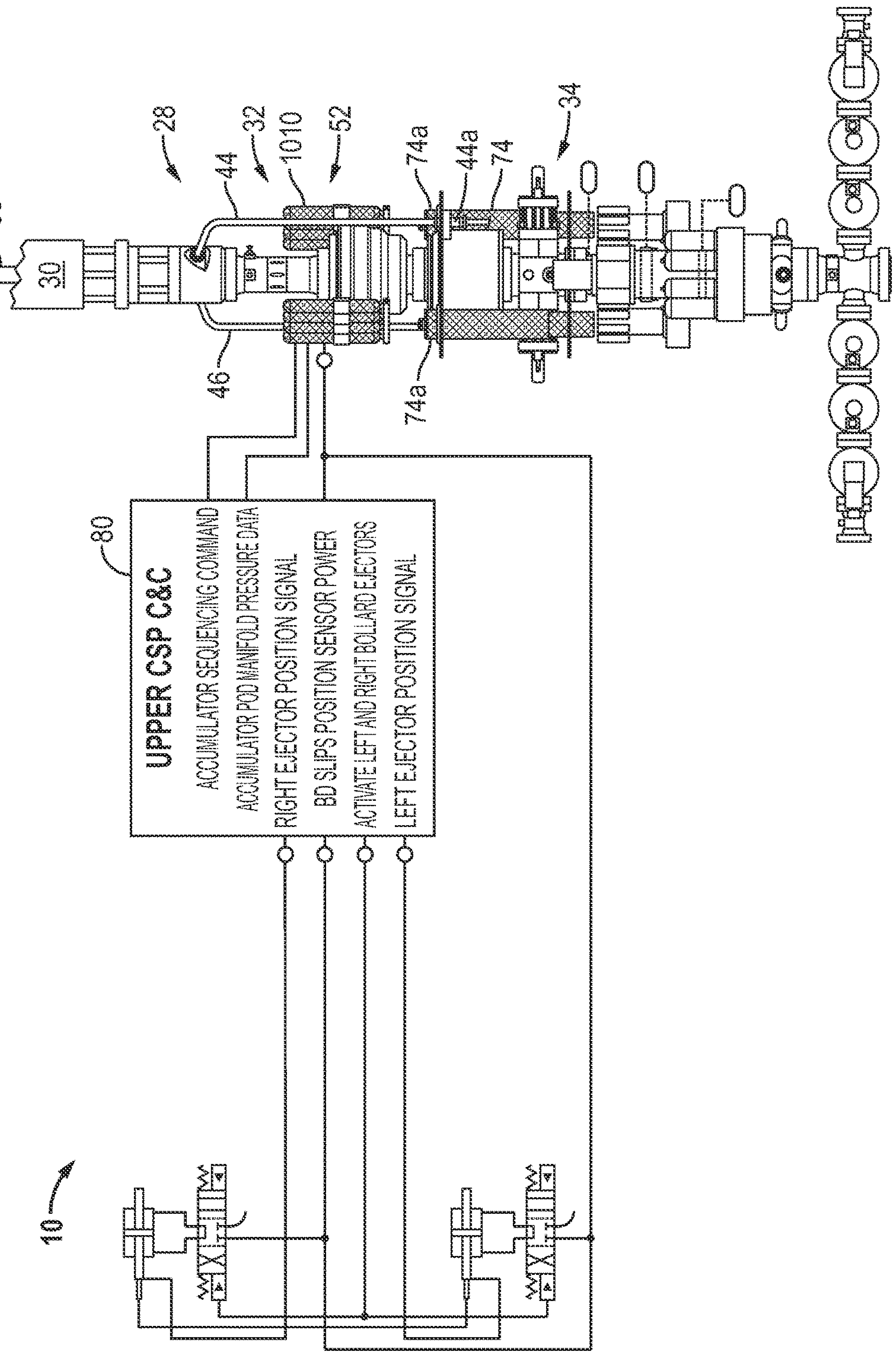
UPPER CSP C&C
ACCUMULATOR SEQUENCING COMMAND
ACCUMULATOR POD MANIFOLD PRESSURE DATA
RIGHT EJECTOR POSITION SIGNAL
BD SLIPS POSITION SENSOR POWER
ACTIVATE LEFT AND RIGHT BOLLARD EJECTORS
LEFT EJECTOR POSITION SIGNAL
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74a

FIG. 13

FIG. 14

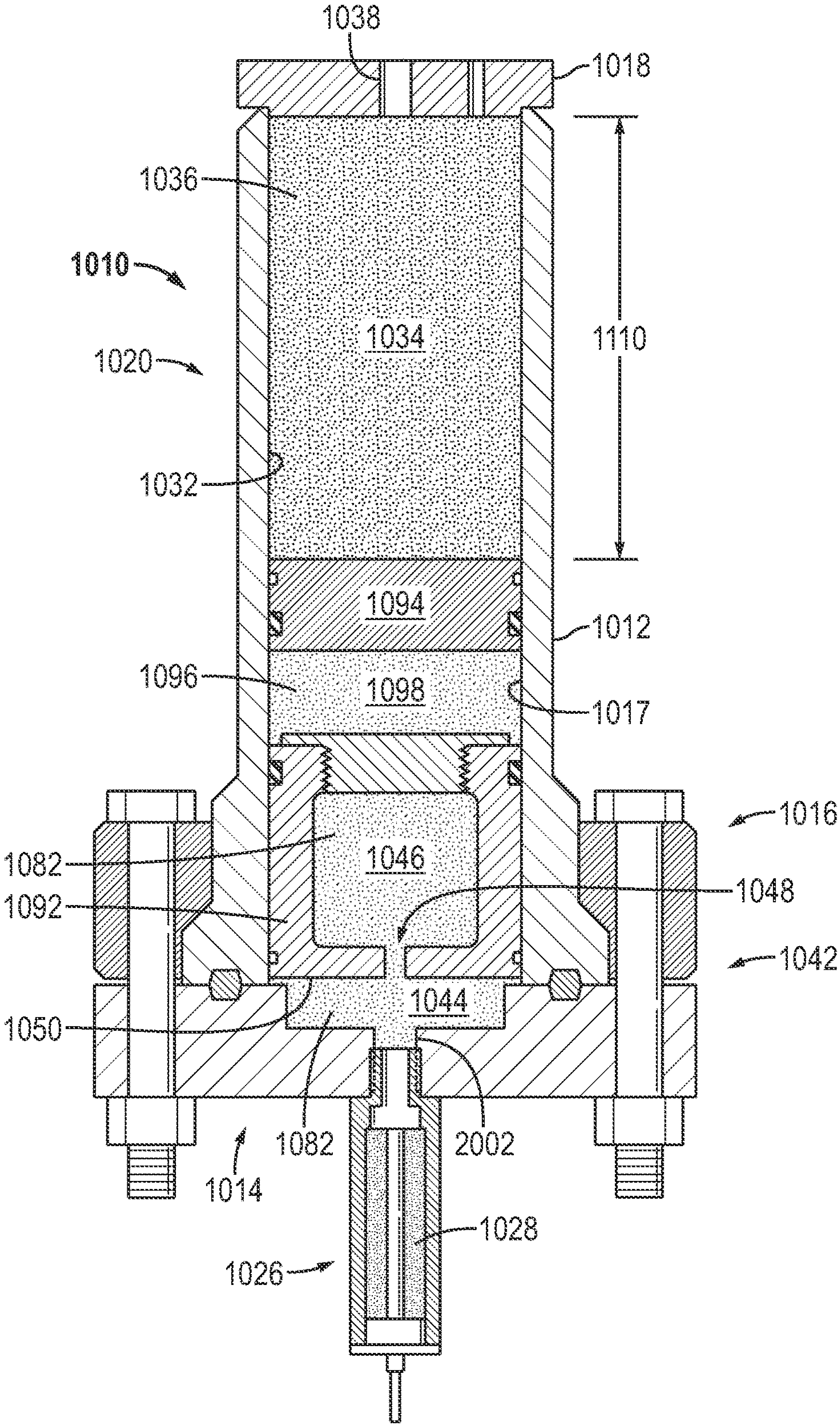
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FIG. 15

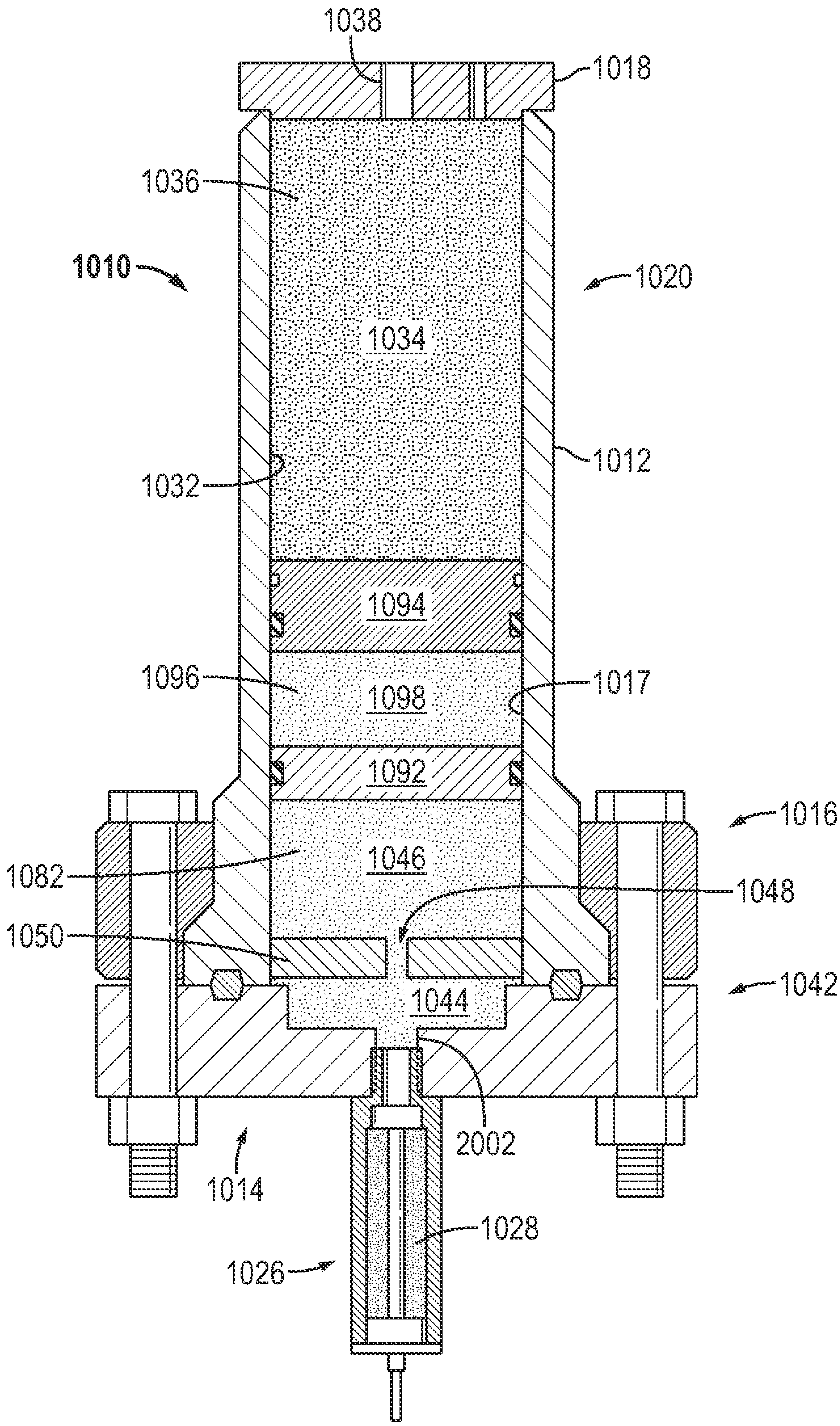
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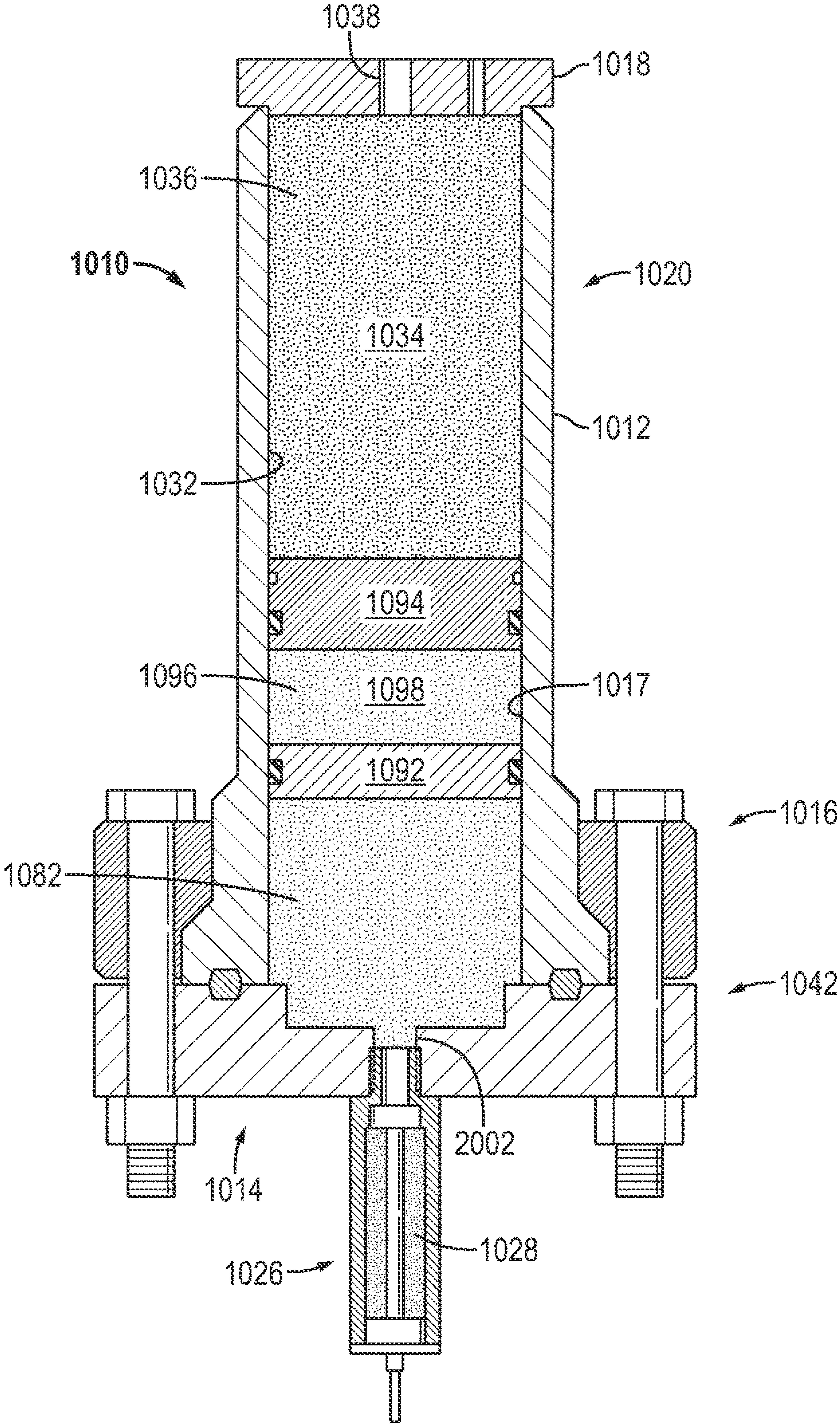
FIG. 16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MULTIPLE GAS GENERATOR DRIVEN PRESSURE SUPPLY

BACKGROUND

This section provides background information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

Pre-charged hydraulic accumulators are utilized in many different industrial applications to provide a source of hydraulic pressure and operating fluid to actuate devices such as valves. It is common for installed pre-charged hydraulic accumulators to be connected to or connectable to a source of hydraulic pressure to recharge the hydraulic accumulator due to leakage and/or use.

SUMMARY

A pressure supply device in accordance to one or more aspects includes an elongated body having an internal bore extending from a power end to a discharge end having a discharge port, two or more gas generators connected to the power end and a hydraulic fluid disposed in the bore between a piston and the discharge end. The ignition of one of the gas generators drives the piston to exhaust a partial volume of the hydraulic fluid that is less than the total operational volume of the hydraulic fluid under pressure to operate at a connected device. In accordance to a method a first volume of pressurized hydraulic fluid is exhausted through a discharge port of a pressure supply device in response to igniting a first gas generator and a second volume of pressurized hydraulic fluid is exhausted in response to igniting a second gas generator. An operational device may be actuated to a first position in response to receiving the first volume of pressurized hydraulic fluid or in response to receiving the first and the second volumes of pressurized hydraulic fluid.

This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of various features may be arbitrarily increased or reduced for clarity of discussion.

FIGS. **1** and **3** illustrate multiple gas generator driven pressure supply devices according to one or more aspects of the disclosure.

FIG. **2** is a sectional view of a multiple gas generator driven pressure supply device along the line I-I of FIG. **1**.

FIG. **4** is a schematic illustration of a well system incorporating a multiple gas generator driven pressure supply device according to one or more aspects of the disclosure.

FIG. **5** illustrates an example of a pressure supply device according to one or more aspects of the disclosure that can be utilized as a multiple gas generator driven pressure supply device.

FIG. **6** illustrates a piston according to an embodiment of the disclosure.

FIGS. **7-9** illustrate an example of a pressure supply device in various positions that can be utilized as a multiple gas generator driven pressure supply device.

FIGS. **10** and **11** illustrate a subsea well system and subsea well safety system in which multiple gas generator driven pressure supply devices can be utilized.

FIG. **12** illustrates a subsea well system incorporating a multiple gas generator driven pressure supply device according to one or more aspects of the disclosure.

FIG. **13** is a schematic diagram illustrating operation of a multiple gas generator driven pressure supply device according to one or more aspects of the disclosure.

FIGS. **14** to **16** illustrate gas driven pressure supply devices according to one or more aspects of the disclosure having a pair of pistons separated by a compressible medium.

DETAILED DESCRIPTION

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

A gas generator driven pressure supply device is disclosed that provides a useable storage of hydraulic fluid that can be pressurized for use on demand. The gas generator driven pressure supply device can be utilized to establish the necessary hydraulic power to drive and operate hydraulic and mechanical operational devices and systems and it may be utilized in conjunction with or in place of pre-charged hydraulic accumulators. Examples of utilization of the gas generator driven pressure supply device are described with reference to well systems, in particular safety systems; however, use of the gas generator driven pressure supply devices is not limited to well systems, subsea systems and environments or to safety systems. For example, and without limitation, gas generator driven pressure supply devices are utilized to operate valves, bollards, pipe rams, and pipe shears. According to embodiments disclosed herein, the gas generator driven pressure supply device can be located subsea and remain in place without requiring hydraulic pressure recharging.

FIGS. **1** and **2** illustrate a gas generator driven pressure supply device, generally denoted by the numeral **1010**, in accordance to one or more embodiments. The pressure supply device **1010** is driven by a gas generator **1026** and in particular by multiple gas generators **1026**. FIG. **2** is a sectional view of the pressure supply device **1010** along the line I-I in FIG. **1**. With reference in particular to FIGS. **1-3**, the pressure supply device **1010** has a body **1012** extending axially substantially from a first end **1014**, or power end, of a pyrotechnic section **1016** to a discharge end **1018** of a hydraulic section **1020**. Body **1012** may be constructed of one or more sections and forms a bore **1032**. A piston **1030** is moveably disposed in the bore **1032** and separates a hydraulic chamber **1034** formed between the piston and the discharge end from a gas chamber **1017** on the opposite side of the piston. The hydraulic chamber **1034** is filled with a fluid **1036**, e.g., non-compressible fluid, e.g., oil, water, or gas. Fluid **1036** is generally described herein as a liquid or hydraulic fluid, however, it is understood that a gas can be utilized for some embodiments. Fluid **1036** is not pre-charged and stored in hydraulic chamber **1034** at the operating pressure, but instead driven to the required operating pressure by gas generators **1026**. Hydraulic chamber **1034** can be filled with fluid **1036** for example through the discharge port **1038** located at the discharge end **1018** of the bore. A relief port **1070** is illustrated in FIG. **2** through which can be utilized to relieve pressure from the hydraulic chamber during fluid fill operations. The location of vent port **1070** can vary. As will be understood by those skilled in the art with benefit of this disclosure port **1070** will include a valve or plug during operations.

Multiple pressure generators **1026** (i.e., gas generators), comprising a pyrotechnic (e.g., propellant) charge **1028**, is connected at first end **1014** and is in communication with the gas chamber **1017** (i.e., expansion chamber) of pyrotechnic section **1016**. The propellant may be for example a solid propellant. The depicted pressure generator **1026** comprises an initiator (e.g., ignitor) **1029** connected to the charge **1028** and extending via an electrical conductor to an electrical connector **1027**. Upon ignition of pyrotechnic charge **1028**, high pressure gas **1082** is produced and expands in gas chamber **1017** and urges piston **1030** toward discharge end **1018** thereby pressurizing fluid **1036** and exhausting the pressurized fluid through discharge end **1018** to operate the connected operational device.

With reference to FIGS. **1-4**, the gas generators **1026** are formed as cartridges with the propellant **1028** located in a breech chamber **1044** of a housing **1013**. The breech chamber is in fluid connection or communication with the gas chamber **1017**. In FIG. **2**, the housing **1013** is connected directly to the body **1012** for example by threading. In FIG. **3** the gas generators **1026** are connected to body via a manifold or conduit **1015**. As will be noted the gas generators **1026** are operationally connected to the pressure supply device in parallel and can be operated independent of one another.

Operation of a multiple gas generator driven pressure supply device **1010** in a well system **12** is now described with reference to FIG. **4**. Well system **12**, which may be a land based or subsea well system, includes an operational device **1100** that is operated in response to hydraulic pressure. Operational device **1100** may include without limitation devices and tools such as valves, rams, and shears. The operational device may be disposed in a wellbore or be in operational connection or communication with a wellbore, for example to a tubular that extends into the wellbore. The operational devices **1100** may be operated between two or more positions, for example, in some embodiments a device may be operated through various open flow positions. FIG. **4** illustrates the piston **1030** being moved in sequential steps along the stroke length **1110** of the pressure supply device in response to sequential ignition of the multiple gas generators **1026**. For example, a signal may be sent from controller **80** to a first one of the multiple gas generators **1026** and in response to ignition of the first gas generator the piston moves from a first position **1110***a* to a second position **1110***b*. The movement of the piston forces a volume of the hydraulic fluid out of the discharge port **1038** through the flow control device **1040** and to the operational device **1100**. The first volume of hydraulic fluid discharged may actuate the operational device to a first position or an additional volume of hydraulic fluid may be needed to actuate the operational device **1100**, for example the first and second volumes of pressurized hydraulic fluid may be required to actuate the device **1100** to a first position. The controller **80** may ignite a second gas generator **1026** to move the piston from the second position **1110***b* to position **1110***c* as needed. Similarly, the controller can operate the third gas generator to move the piston from the third position to a fourth position **1110***d*. Multiple gas generators **1026** may be utilized as opposed to a single gas generator for various purposes. As noted, in some systems **12** the operational device **1100** may be operable between two or more positions. Accordingly, the pressure supply device **1010** may contain a sufficient volume of hydraulic fluid for two or more actuations of a single operational device **1100** or to actuate more than one operational device. Multiple gas generators may also provide for a safety backup, for example, if a first gas generator does not ignite or does not move the piston a sufficient distance to provide the volume and/or pressure of hydraulic fluid required, then a second gas generator can be actuated.

As will be understood by those skilled in the art with benefit of this disclosure, multiple gas generators **1026** may be utilized various pressure supply device configurations. For example, FIGS. **5-9**, illustrate and describe embodiments of pressure supply devices **1010** with relation to a single gas generator **1026** as disclosed in U.S. Published Patent Application 2013/0220161, which is incorporated herein by reference.

FIG. **5** is a sectional view of an example of a pressure supply device **1010** according to one or more embodiments. Pressure supply device **1010** comprises an elongated body **1012** extending substantially from a first end **1014** of pyrotechnic section **1016** to a discharge end **1018** of a hydraulic section **1020**. As will be understood by those skilled in the art with benefit of this disclosure, body **1012** may be constructed of one or more sections (e.g., tubular sections). In the depicted embodiment, pyrotechnic section **1016** and hydraulic section **1020** are connected at a threaded joint **1022** (e.g., double threaded) having a seal **1024**. In the depicted embodiment, threaded joint **1022** provides a high pressure seal (e.g., hydraulic seal and/or gas seal).

A pressure generator **1026** (i.e., gas generator), comprising a pyrotechnic (e.g., propellant) charge **1028**, is connected at first end **1014** (e.g., power end) and is in communication with the gas chamber **1017** (i.e., expansion chamber) of pyrotechnic section **1016**. The depicted pressure generator **1026** comprises an initiator (e.g., igniter) **1029** connected to pyrotechnic charge **1028** and extending via electrical conductor **1025** to an electrical connector **1027**. In this example, electrical connector **1027** is a wet-mate connector for connecting to an electrical source for example in a sub-sea, high pressure environment.

A piston **1030** is moveably disposed within a bore **1032** of the hydraulic section **1020** of body **1012**. A hydraulic fluid chamber **1034** is formed between piston **1030** and discharge end **1018**. Hydraulic chamber **1034** is filled with a fluid **1036**, e.g., non-compressible fluid, e.g., oil, water, or gas. Fluid **1036** is generally described herein as a liquid or hydraulic fluid, however, it is understood that a gas can be utilized for some embodiments. Hydraulic chamber **1034** can be filled with fluid **1036** for example through a port. Fluid **1036** is not pre-charged and stored in hydraulic chamber **1034** at the operating pressure.

A discharge port **1038** is in communication with discharge end **1018** to communicate the pressurized fluid **1036** to a hydraulic circuit having an operational device (e.g., valve, rams, bollards, etc.). In the depicted embodiment, discharge port **1038** is formed by a member **1037**, referred to herein as cap **1037**, connected at discharge end **1018** for example by a bolted flange connection. A flow control device **1040** is located in the fluid flow path of discharge port **1038**. In this example, flow control device **1040** is a one-way valve (i.e., check valve) permitting fluid **1036** to be discharged from fluid hydraulic chamber **1034** and blocking backflow of fluid into hydraulic chamber **1034**. A connector **1039** (e.g., flange) is depicted at discharge end **1018** to connect hydraulic chamber **1034** to an operational device for example through a manifold. According to embodiments, pressure supply device **1010** is configured to be connected to a subsea well system for example by a remote operated vehicle.

Upon ignition of pyrotechnic charge **1028**, high pressure gas is produced and expands in gas chamber **1017** and urges piston **1030** toward discharge end **1018** thereby pressurizing fluid **1036** and exhausting the pressurized fluid **1036** through discharge end **1018** and flow control device **1040** to operate the connected operational device.

Piston **1030** is configured to operate in a pyrotechnic environment and in a hydraulic environment. A non-limiting example of piston **1030**, referred to also as a hybrid piston, is described with reference to FIGS. **5** and **6**. Piston **1030**, depicted in FIGS. **5** and **6**, includes a pyrotechnic end, or end section, **1056** and a hydraulic end, or end section **1058**. Pyrotechnic end **1056** faces pyrotechnic charge **1028** and hydraulic end **1058** faces discharge end **1018**. Piston **1030** may be constructed of a unitary body or may be constructed in sections (see, e.g., FIGS. **7-9**) of the same or different material. In this embodiment, piston **1030** comprises a ballistic seal (i.e., obturator seal) **1060**, a hydraulic seal **1062**, and a first and a second piston ring set **1064**, **1066**. According to an embodiment, ballistic seal **1060** is located on outer surface **1068** of pyrotechnic end **1056** of piston **1030**. Ballistic seal **1060** may provide centralizing support for piston **1030** in bore **1032** and provide a gas seal to limit gas blow by (e.g., depressurization). First piston ring set **1064** is located adjacent to ballistic seal **1060** and is separated from the terminal end of pyrotechnic end **1056** by ballistic seal **1060**. Second piston ring set **1066** is located proximate the terminal end of hydraulic end section **1058**. A hydraulic seal **1062** is located between the first piston ring set and the second piston ring set in this non-limiting example of piston **1030**.

According to some embodiments, one or more pressure control devices **1042** are positioned in gas chamber **1017** for example to dampen the pressure pulse and/or to control the pressure (i.e., operating or working pressure) at which fluid **1036** is exhausted from discharge port **1038**. In the embodiment depicted in FIG. **5**, gas chamber **1017** of pyrotechnic section **1016** includes two pressure control devices **1042**, **1043** dividing gas chamber **1017** into three chambers **1044**, **1046** and **1045**. First chamber **1044**, referred to also as breech chamber **1044**, is located between first end **1014** (e.g., the connected gas generator **1026**) and first pressure control device **1042** and a snubbing chamber **1046** is formed between pressure control devices **1042**, **1043**. Additional snubbing chambers can be provided when desired.

First pressure control device **1042** comprises an orifice **1048** formed through a barrier **1050** (e.g., orifice plate). Barrier **1050** may be constructed of a unitary portion of the body of pyrotechnic section **1016** or it may be a separate member, see e.g. FIGS. **1-3**, connected with pyrotechnic section. Second pressure control device **1043** comprises an orifice **1047** formed through a barrier **1049**. Barrier **1049** may be a continuous or unitary portion of the body of pyrotechnic section **1016** or may be a separate member connected within the pyrotechnic section. The size of orifices **1048**, **1047** can be sized to provide the desired working pressure of the discharged hydraulic fluid **1036**.

For example, in FIG. **5** pyrotechnic section **1016** includes two interconnected tubular sections or subs. In this embodiment, the first tubular sub **1052** (e.g., breech sub), includes first end **1014** and breech chamber **1044**. The second tubular sub **1054**, also referred to as snubbing sub **1054**, forms snubbing chamber **1046** between the first pressure control device **1042**, i.e., breech orifice, and the second pressure control device **1043**, i.e., snubbing orifice. For example, piston **1030** and snubbing pressure control device **1043** may be inserted at the threaded joint **1022** between hydraulic section **1020** and snubbing sub **1054** as depicted in FIG. **5**, formed by a portion of body **1012**, and or secured for example by soldering or welding as depicted in FIGS. **7-9** (e.g., connector **1072**, FIG. **7**). The breech pressure control device **1042** can be inserted at the threaded joint **1022** between breech sub **1052** and snubbing sub **1054**. In the FIG. **5** embodiment, barrier **1050** and/or barrier **1049** may be retained between the threaded connection **1022** of adjacent tubular sections of body **1012** and/or secured for example by welding or soldering (e.g., connector **1072** depicted in FIG. **7**).

In the embodiment of FIG. **5**, a rupture device **1055** closes an orifice **1048**, **1047** of at least one of pressure control devices **1042**, **1043**. In the depicted example, rupture device **1055** closes orifice **1047** of second pressure control device **1043**, adjacent to hydraulic section **1020**, until a predetermined pressure differential across rupture device **1055** is achieved by the ignition of pyrotechnic charge **1028**. Rupture device **1055** provides a seal across orifice **1047** prior to connecting pyrotechnic section **1016** with hydraulic section **1020** and during inactivity, for example to prevent fluid **1036** leakage to seep into pyrotechnic section **1016**.

According to some embodiments, a pressure compensation device (see, e.g., FIGS. **7-9**) may be connected for example with gas chamber **1017** of pyrotechnic section **1016**. When being located subsea, the pressure compensation device substantially equalizes the pressure in gas chamber **1017** with the environmental hydrostatic pressure. In accordance to some embodiments, the pressure supply devices do not utilized a pressure compensation device.

According to one or more embodiments, pressure supply device **1010** may provide a hydraulic cushion to mitigate impact of piston **1030** at discharge end **1018**, for example against cap **1037**. In the example depicted in FIG. **5**, the cross-sectional area of discharge port **1038** decreases from an inlet end **1051** to the outlet end **1053**. The tapered discharge port **1038** may act to reduce the flow rate of fluid **1036** through discharge port **1038** as piston **1030** approaches discharge end **1018** and providing a fluid buffer that reduces the impact force of piston **1030** against cap **1037**.

A hydraulic cushion at the end of the stroke of piston **1030** may be provided for example, by a mating arrangement of piston **1030** and discharge end **1018** (e.g., cap **1037**). For example, as illustrated in FIG. **5** and with additional reference to FIG. **6**, end cap **1037** includes a sleeve section **1084** disposed inside of bore **1032** of hydraulic section **1020**. Sleeve section **1084** has a smaller outside diameter than the inside diameter of bore **1032** providing an annular gap **1086**. Piston **1030** has a cooperative hydraulic end **1058** that forms a cavity **1088** having an annular sidewall **1090** (e.g., skirt). Annular sidewall **1090** is sized to fit in annular gap **1086** disposed inlet end **1051** and sleeve **1084** in cavity **1088**. Hydraulic fluid **1036** disposed in gap **1086** will cushion the impact of piston **1030** against end cap **1037**. It is to be noted that discharge port **1038** does not have to be tapered to provide a hydraulic cushion.

In some embodiments (e.g., see FIGS. **7-9**), hydraulic chamber **1034** may be filled with a volume of hydraulic fluid **1036** in excess of the volume required for the particular installation of pressure supply device **1010**. The excess volume of fluid **1036** can provide a cushion separating piston **1030** from discharge end **1018** at the end of the stroke of piston **1030**.

FIG. **7** is a sectional view of a pressure supply device **1010** according to one or more embodiments illustrated in a first position for example prior to being deployed at a depth subsea. Pressure supply device **1010** comprises an elongated body **1012** extending from a first end **1014** of a pyrotechnic section **1016** to discharge end **1018** of a hydraulic section **1020**. In the depicted example pyrotechnic section **1016** and hydraulic section **1020** are connected at a threaded joint **1022** having at least one seal **1024**.

Hydraulic section **1020** comprises a bore **1032** in which a piston **1030** is movably disposed. The piston **1030** depicted in FIGS. **7-9** is a hybrid piston having a pyrotechnic end section **1056** having a ballistic seal **1060** and hydraulic end section **1058** having a hydraulic seal **1062**. In the depicted embodiment, piston **1030** is a two-piece construction. Pyrotechnic end section **1056** and hydraulic end section **1058** are depicted coupled together by a connector, generally denoted by the numeral **1057** in FIG. **9**. Connector **1057** is depicted as a bolt, e.g., threaded bolt, although other attaching devices and mechanism (e.g., adhesives may be utilized).

Hydraulic chamber **1034** is formed between piston **1030** and discharge end **1018**. A flow control device **1040** is disposed with discharge port **1038** of discharge end **1018** substantially restricting fluid flow to one-direction from hydraulic chamber **1034** through discharge port **1038**. Hydraulic chamber **1034** may be filled with hydraulic fluid **1036** for example through discharge port **1038**. Port **1070** (e.g., valve) is utilized to relieve pressure from hydraulic chamber **1034** during fill operations or to drain fluid **1036** for example if an un-actuated pressure supply device **1010** is removed from a system.

In some embodiments, pyrotechnic section **1016** includes the breech chamber **1044** (e.g., the gas generator) and a snubbing chamber **1046**. Gas generator **1026** is illustrated connected, for example by bolted interface in FIGS. **5**, **7-9**, to first end **1014** disposing pyrotechnic charge **1028** into breech chamber **1044**. Breech chamber **1044** and snubbing chamber **1046** are separated by pressure control device **1042** which is illustrated as an orifice **1048** formed through breech barrier **1050**. In this non-limiting example, breech barrier **1050** is formed by a portion of body **1012** forming pyrotechnic section **1016**. Breech orifice **1048** can be sized for the desired operating pressure of pressure supply device **1010**.

Snubbing chamber **1046** is formed in pyrotechnic section **1016** between barrier **1050** and a snubbing barrier **1049** of second pressure control device **1043**. Pressure control device **1043** has a snubbing orifice **1047** formed through snubbing barrier **1049**. In FIG. **7** the snubbing barrier **1049** is illustrated secured in place by a connector **1072**. In this example, connector **1072** is a solder or weld to secure barrier **1049** (i.e., plate) in place and provide additional sealing along the periphery of barrier **1049**. Snubbing orifice **1047** may be sized for the fluid capacity and operating pressure of the particular pressure supply device **1010** for example to dampen the pyrotechnic charge pressure pulse. A rupture device **1055** is depicted disposed with the orifice **1047** to seal the orifice and therefore gas chambers **1044**, **1046** during inactivity of the deployed pressure supply device **1010**. Rupture device **1055** can provide a clear opening during activation of pressure supply device **1010** and burning of charge **1028**. In FIGS. **7-9** a vent **1074**, i.e., valve, is illustrated in communication with gas chamber **1017** to relieve pressure from the gas chambers prior to disassembly after pressure supply device **1010** has been operated.

FIGS. **7** to **9** illustrate a pressure compensation device **1076** in operational connection with the gas chambers, breech chamber **1044** and snubbing chamber **1046**, to increase the pressure in the gas chambers in response to deploying pressure supply device **1010** subsea. In the depicted embodiment, pressure compensator **1076** includes one or more devices **1078** (e.g. bladders) containing a gas (e.g., nitrogen). Bladders **1078** are in fluid connection with gas chambers **1017** (e.g., chambers **1044**, **1046**, etc.) for example through ports **1080**. In FIG. **8**, the pressure supply device **1010** is depicted deployed subsea (see, e.g., FIGS. **11-12**) prior to being activated. In response to the hydrostatic pressure at the subsea depth of pressure supply device bladders **1078** have deflated thereby pressurizing breech chamber **1044** and snubbing chamber **1046**. Again, in some embodiments pressure compensation devices and systems are not utilized.

FIG. **9** illustrates an embodiment of pressure supply device **1010** after being activated. With reference to FIGS. **8** and **9**, pressure supply device **1010** is activated by igniting pyrotechnic charge **1028**. The ignition generates gas **1082** which expands in breech chamber **1044** and snubbing chamber **1046**. The pressure in the gas chambers ruptures rupture device **1055** and the expanding gas acts on pyrotechnic side **1056** of piston **1030**. Piston **1030** is moved toward discharge end **1018** in response to the pressure of gas **1082** thereby discharging pressurized fluid **1036** through discharge port **1038** and flow control device **1040**. In FIG. **9**, piston **1030** is illustrated spaced a distance apart from discharge end **1018**. In accordance to one or more embodiments, at least a portion of the volume of fluid **1036** remaining in hydraulic fluid chamber **1034** is excess volume supplied to provide a space (i.e., cushion) between piston **1030** and discharge end **1018** at the end of the stroke of piston **1030**.

Pressure supply device **1010** can be utilized in many applications wherein an immediate and reliable source of pressurized fluid is required. Pressure supply device **1010** provides a sealed system that is resistant to corrosion and that can be constructed of material for installation in hostile environments. Additionally, pressure supply device **1010** can provide a desired operating pressure level without regard to the ambient environmental pressure (i.e., no pressure compensation). Multiple gas generators may be utilized to drive the pressure supply device.

A method of operation is now described with reference to FIGS. **10-13** which illustrate a subsea well system **12** in which one or more pressure supply devices are utilized. The pressure supply devices and systems of FIGS. **5-13** are disclosed in U.S. Patent Application Publication No. 2013/0220161, which is incorporated herein by reference.

FIG. **10** is a schematic illustration of a well safing system, generally denoted by the numeral **10**, being utilized in a subsea well system **12**. The depicted subsea well system is a non-limiting example of a system in which the multiple gas generator driven pressure supply device may be utilized. In the depicted embodiment drilling system **12** includes a BOP stack **14** which is landed on a subsea wellhead **16** of a well **18** (i.e., wellbore) penetrating seafloor **20**. BOP stack **14** conventionally includes a lower marine riser package

("LMRP") **22** and blowout preventers ("BOP") **24**. The depicted BOP stack **14** also includes subsea test valves ("SSTV") **26**. As will be understood by those skilled in the art with benefit of this disclosure, BOP stack **14** is not limited to the devices depicted.

Subsea well safing system **10** comprises safing package, or assembly, referred to herein as a catastrophic safing package ("CSP") **28** that is landed on BOP system **14** and operationally connects a riser **30** extending from platform **31** (e.g., vessel, rig, ship, etc.) to BOP stack **14** and thus well **18**. CSP **28** comprises an upper CSP **32** and a lower CSP **34** that are configured to separate from one another in response to initiation of a safing sequence thereby disconnecting riser **30** from the BOP stack **14** and well **18**, for example as illustrated in FIG. **11**. The safing sequence is initiated in response to parameters indicating the occurrence of a failure in well **18** with the potential of leading to a blowout of the well. Subsea well safing system **10** may automatically initiate the safing sequence in response to the correspondence of monitored parameters to selected safing triggers. According to one or more embodiments, CSP **28** includes one or more pressure supply devices **1010** (see, e.g., FIGS. **12** and **13**) to provide hydraulic pressure on demand to operate one or more of the well system devices (e.g., valves, connectors, ejector bollards, rams, and shears).

Wellhead **16** is a termination of the wellbore at the seafloor and generally has the necessary components (e.g., connectors, locks, etc.) to connect components such as BOPs **24**, valves (e.g., test valves, production trees, etc.) to the wellbore. The wellhead also incorporates the necessary components for hanging casing, production tubing, and subsurface flow-control and production devices in the wellbore.

LMRP **22** and BOP stack **14** are coupled together by a connector that is engaged with a corresponding mandrel on the upper end of BOP stack **14**. LMRP **22** typically provides the interface (i.e., connection) of the BOPs **24** and the bottom end **30***a* of marine riser **30** via a riser connector **36** (i.e., riser adapter). Riser connector **36** may further comprise one or more ports for connecting fluid (i.e., hydraulic) and electrical conductors, i.e., communication umbilical, which may extend along (exterior or interior) riser **30** from the drilling platform located at surface **5** to subsea drilling system **12**. For example, it is common for a well control choke line **44** and a kill line **46** to extend from the surface for connection to BOP stack **14**.

Riser **30** is a tubular string that extends from the drilling platform **31** down to well **18**. The riser is in effect an extension of the wellbore extending through the water column to drilling vessel **31**. The riser diameter is large enough to allow for drill pipe, casing strings, logging tools and the like to pass through. For example, in FIGS. **10** and **11**, a tubular **38** (e.g., drill pipe) is illustrated deployed from drilling platform **31** into riser **30**. Drilling mud and drill cuttings can be returned to surface **5** through riser **30**. Communication umbilical (e.g., hydraulic, electric, optic, etc.) can be deployed exterior to or through riser **30** to CSP **28** and BOP stack **14**. A remote operated vehicle ("ROV") **124** is depicted in FIG. **11** and may be utilized for various tasks including installing and removing pressure supply devices **1010**.

Refer now to FIG. **12** which illustrates a subsea well safing package **28** according to one or more embodiments in isolation. CSP **28** depicted in FIG. **12** is further described with reference to FIGS. **10** and **11**. In the depicted embodiment, CSP **28** comprises upper CSP **32** and lower CSP **34**. Upper CSP **32** comprises a riser connector **42** which may include a riser flange connection **42***a*, and a riser adapter **42***b* which may provide for connection of communication umbilicals and extension of the communication umbilicals to various CSP **28** devices and/or BOP stack **14** devices. For example, a choke line **44** and a kill line **46** are depicted extending from the surface with riser **30** and extending through riser adapter **42***b* for connection to the choke and kill lines of BOP stack **14**. CSP **28** comprises a choke stab **44***a* and a kill line stab **46***a* for interconnecting the upper portion of choke line **44** and kill line **46** with the lower portion of choke line **44** and kill line **46**. Stabs **44***a*, **46***a* can provide for disconnecting from the stab and kill lines during safing operations; and during subsequent recovery and reentry operations reconnecting to the choke and kill lines via stabs **44***a*, **46***a*. CSP **28** comprises an internal longitudinal bore **40**, depicted in FIG. **12** by the dashed line through lower CSP **34**, for passing tubular **38**. Annulus **41** is formed between the outside diameter of tubular **38** and the diameter of bore **40**.

Upper CSP **32** further comprises slips **48** (i.e., safety slips) configured to close on tubular **38**. Slips **48** are actuated in the depicted embodiment by hydraulic pressure from a hydraulic accumulator **50** and/or a pressure supply device **1010**. In the depicted embodiment, CSP **28** comprises a plurality of hydraulic accumulators **50** and/or pressure supply devices **1010** which may be interconnected in pods, such as upper hydraulic accumulator pod **52**. A pressure supply device **1010** located in the upper hydraulic accumulator pod **52** is hydraulically connected to one or more devices, such as slips **48**.

Lower CSP **34** comprises a connector **54** to connect to BOP stack **14**, for example, via riser connector **36**, rams **56** (e.g., blind rams), high energy shears **58**, lower slips **60** (e.g., bi-directional slips), and a vent system **64** (e.g., valve manifold). Vent system **64** comprises one or more valves **66**. In this embodiment, vent system **64** comprise vent valves (e.g., ball valves) **66***a*, choke valves **66***b*, and one or more connection mandrels **68**. Valves **66***b* can be utilized to control fluid flow through connection mandrels **68**. For example, a recovery riser **126** is depicted connected to one of mandrels **68** for flowing effluent from the well and/or circulating a kill fluid (e.g., drilling mud) into the well.

In the depicted embodiment, lower CSP **34** further comprises a deflector device **70** (e.g., impingement device, shutter ram) disposed above vent system **64** and below lower slips **60**, shears **58**, and blind rams **56**. Lower CSP **34** includes a plurality of hydraulic accumulators **50** and/or pressure supply devices **1010** arranged and connected in one or more lower hydraulic pods **62** for operations of various devices of CSP **28**. In the embodiment of FIG. **12**, a chemical source **76**, e.g., methanol is illustrated for injection into the system for example to prevent hydrate formation.

Upper CSP **32** and lower CSP **34** are detachably connected to one another by a connector **72**. In FIG. **11**, the illustrated connector **72** includes a first connector portion **72***a* disposed with the upper CSP **32** and a second connector portion **72***b* disposed with the lower CSP **34**. An ejector device **74** (e.g., ejector bollards) is operationally connected between upper CSP **32** and lower CSP **34** to separate upper CSP **32** and riser **30** from lower CSP **34** and BOP stack **14** after connector **72** has been actuated to the unlocked position. Ejector device **74** can be actuated by operation of pressure supply device **1010**.

CSP **28** includes a plurality of sensors **84** which can sense various parameters, such as and without limitation, temperature, pressure, strain (tensile, compression, torque), vibration, and fluid flow rate. Sensors **84** further includes, without limitation, erosion sensors, position sensors, and accelerometers and the like. Sensors **84** can be in communication with one or more control and monitoring systems, for example forming a limit state sensor package.

According to one or more embodiments of the invention, CSP **28** comprises a control system **78** which may be located subsea, for example at CSP **28** or at a remote location such as at the surface. Control system **78** may comprise one or more controllers which are located at different locations. For example, in at least one embodiment, control system **78** comprise an upper controller **80** (e.g., upper command and control data bus) and a lower controller **82** (e.g., lower command and controller bus). Control system **78** may be connected via conductors (e.g., wire, cable, optic fibers, hydraulic lines) and/or wirelessly (e.g., acoustic transmission) to various subsea devices (e.g., pressure supply devices **1010**) and to surface (i.e., drilling platform **31**) control systems.

FIG. **13** is a schematic diagram of sequence step, according to one or more embodiments of subsea well safing system **10** illustrating operation of ejector devices **74** (i.e., ejector bollards) to physically separate upper CSP **32** and riser **30** from lower CSP **34** as depicted in FIG. **11**. For example, ejector devices **74** may include piston rods **74*a*** which extend to push the upper CSP **32** away from lower CSP **34** in the depicted embodiment. FIG. **11** illustrates piston rod **74*a*** in an extended position. In the embodiment of FIG. **13**, actuation of ejector devices **74** is provided by upper controller **80** sending a signal activating a multiple gas driven pressure supply device **1010** located for example in upper accumulator pod **52** to direct the operating pressure via pressurized hydraulic fluid to ejector devices **74** (i.e., operational device). In accordance to an embodiment, the ejector devices **74** may be actuated in response to receiving a first volume of pressurized hydraulic fluid that is discharged from a pressure supply device **1010** by ignition of a single gas generator. In some embodiments, operation of the ejector devices may require receiving pressurized hydraulic fluid in response to the ignition of more than one of the gas generators of a single pressure supply device; for example the two or more gas generators may be ignited simultaneously or in sequence. In some embodiments, the ejector devices may be actuated to a first position in response to ignition of a first gas generator and actuated to a second position in response to receiving a hydraulic signal from ignition of a second gas generator.

Referring also to FIGS. **1-9**, an electronic signal is transmitted from controller **80** and received at one or more of the gas generators **1026**. The firing signal may be an electrical or hydraulic pulse and/or coded signal. In response to receipt of the firing signal, the ignitor ignites the pyrotechnic charge, e.g., solid propellant, thereby generating gas **1082** that drives the piston toward the discharge end thereby pressurizing hydraulic fluid **1036** and discharging a volume of pressurized hydraulic fluid through discharge port to the operation device, e.g., ejector devices **74**. If the first gas generator does not ignite or otherwise fails, a second gas generator can be ignited to discharge the hydraulic fluid as needed. In accordance to some embodiments a second gas generator **1026** can be operated to advance the stroke of the piston and discharge an additional volume of hydraulic fluid as need to actuate the operation device, for example to actuate the operated device to an additional position. Similarly, as described above with reference to FIG. **4**, one or more of the multiple gas generator pressure supply devices **1010** may be actuated to operate another one of the well system operational devices **1100** such as, and without limitation to, valves, slips, rams, shears and locks.

Refer now to FIGS. **14-16** illustrating aspects of pressure supply devices **1010** according to one or more embodiments of this disclosure. As will be understood by those skilled in the art with benefit of this disclosure, pressure supply devices **1010** illustrated in FIGS. **14-16** dampen the initial pressure pulse produced by the propellant **1028** of the gas generator to mitigate or eliminate the pressure shock in the hydraulic chamber **1034** and to the hydraulic circuit and to the downstream operated hydraulic device. FIGS. **14-16** illustrate non-limiting aspects of pressure supply devices in accordance to this disclosure.

The pressure supply devices **1010** illustrated in FIGS. **14-16** each include a pair of pistons **1092**, **1094** moveably disposed in the bore **1032** of body **1012**. Pistons **1092**, **1094** are separated by a compressible medium or fluid **1096**, for example silicon. Compressible medium **1096** is disposed in bore **1032** in a space **1098** between the first piston **1092** and the second piston **1094**. The first piston **1092** separates the gas chamber **1017** from the compressible medium **1096** and space **1098**. Second piston **1094** separates the hydraulic chamber **1034** and incompressible hydraulic fluid **1036** from the compressible medium **1096** and space **1098**.

With reference to FIG. **14**, gas generator **1026** is connected at an inlet port **2002** to discharge pressurized gas **1082** when it is actuated (e.g., propellant **1028** burns) into the gas chamber **1017**. In the embodiment illustrated in FIG. **14**, pressurized gas enters the gas chamber **1017** for example in a first portion or breech chamber **1044**. A snubbing chamber **1046** is formed by the first piston **1092** and is in communication with the gas chamber **1044** through an orifice **1048**. Orifice **1048** is provided for example through a barrier wall **1050** of the first piston oriented toward the first end **1014**. The hydraulic output pressure can be controlled for example by adjusting the size of orifice **1048** (e.g., pressure control device). As will be understood by those skilled in the art with benefit of this disclosure, one or more additional pressure control devices can be positioned between first end **1014** and first piston **1092**. The first piston and orifice **1048** dampens the pressurization of snubbing chamber **1046**. The pressurized gas **1082** acts on first piston **1092** which pressurizes the compressible medium **1096**. Pressurizing the compressible medium **1096** dampens the pressure pulse due to the ignition of propellant **1028** and may also provide energy storage to pressurize the hydraulic chamber **1034**. The second piston **1094** pressurizes the hydraulic fluid **1036** to actuate the hydraulic circuit. The energy stored in the compressible medium may be released to act on the second piston to provide a continuous or substantially constant discharge pressure through the full stroke length **1110** of the second piston **1094**, i.e., pressure supply device **1010**.

FIG. **15** illustrates an embodiment of a pressure supply device **1010** in accordance to one or more embodiments of the disclosure. In FIG. **11** a snubbing chamber **1046** is formed between first piston **1092** and pressure control device **1042**. Pressure control device **1042** includes a barrier **1050** positioned across bore **1032** between first end **1014** and the first piston **1092**. An orifice **1048** is provided through barrier **1050**.

FIG. **16** illustrates an embodiment of a pressure supply device **1010** in accordance to one or more embodiments. In FIG. **16** a pressure control device is not positioned between the gas generator at inlet port **2002** and the first piston **1092**. It is noted that inlet port **2002** may be utilized to throttle the produced pressurized gas **1082**. Additionally, the size of gas chamber **1017** may serve as a buffer volume to dampen the pressure pulse due to the ignited propellant. For example, the volume of gas chamber **1017** may be increased to dampen the pressure pulse acting on the hydraulic fluid and chamber.

The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the disclosure. Those skilled in the art should appreciate that they may readily use the disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the disclosure. The scope of the invention should be determined only by the language of the claims that follow. The term "comprising" within the claims is intended to mean "including at least" such that the recited listing of elements in a claim are an open group. The terms "a," "an" and other singular terms are intended to include the plural forms thereof unless specifically excluded.

What is claimed is:

1. A method of actuating a hydraulically operated device, comprising:

exhausting, in response to a demand to actuate the hydraulically operated device, a first volume of pressurized hydraulic fluid through a discharge port of a pressure supply device in response to igniting a first gas generator of two or more gas generators, wherein the pressure supply device comprises:

an elongated body having an internal bore extending from a power end to a discharge end having the discharge port, the two or more gas generators connected to the power end, and hydraulic fluid disposed in the internal bore between a piston and the discharge end;

exhausting, in response to a demand to actuate the hydraulically operated device, a second volume of pressurized hydraulic fluid through the discharge port in response to igniting a second gas generator of the two or more gas generators;

actuating the hydraulically operated device to a first position in response to receiving the first volume of pressurized hydraulic fluid; and

actuating the hydraulically operated device to a second position in response to receiving the second volume of pressurized hydraulic fluid.

2. The method of claim **1**, wherein the first and the second gas generators comprise a propellant that produces a gas in response to being ignited.

3. The method of claim **1**, wherein the first and second gas generators are connected directly to the power end.

4. The method of claim **1**, wherein the first and the second gas generators are connected to the power end through a conduit.

5. The method of claim **1**, wherein:

the first and the second gas generators comprise a propellant that produces a gas in response to being ignited; and

the first and second gas generators are connected directly to the power end.

6. The method of claim **1**, wherein:

the first and the second gas generators comprise a propellant that produces a gas in response to being ignited; and

the first and the second gas generators are connected to the power end through a conduit.

7. The method of claim **1**, wherein the hydraulically operated device is a valve.

8. The method of claim **1**, wherein the hydraulically operated device is connected in a well system.

9. The method of claim **1**, comprising a one-way valve connected between the discharge port and the hydraulically operated device.

10. The method of claim **1**, wherein the piston separates a hydraulic chamber formed between the piston and the discharge end and a gas expansion chamber on an opposite side of the piston, the hydraulic fluid disposed in the hydraulic chamber.

11. The method of claim **1**, wherein the hydraulically operated device is located subsea.

12. The method of claim **1**, wherein the hydraulically operated device is a ram.

13. The method of claim **1**, comprising a one-way valve connected between the discharge port and the hydraulically operated device; and

the piston separating a hydraulic chamber formed between the piston and the discharge end and a gas expansion chamber formed between the piston and the power end, the hydraulic fluid disposed in the hydraulic chamber.

14. The method of claim **1**, wherein the exhausting the first volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the first gas generator; and

the exhausting the second volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the second gas generator.

15. The method of claim **14**, wherein the hydraulically operated device is connected in a well system.

16. The method of claim **1**, wherein the piston separates a hydraulic chamber formed between the piston and the discharge end and a gas expansion chamber formed between the piston and the power end, the hydraulic fluid disposed in the hydraulic chamber;

the exhausting the first volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the first gas generator being communicated into the gas expansion chamber; and

the exhausting the second volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the second gas generator being communicated into the gas expansion chamber.

17. The method of claim **16**, wherein the hydraulically operated device is connected in a well system.

18. The method of claim **16**, wherein the hydraulically operated device is a ram.

19. The method of claim **1**, comprising a one-way valve connected between the discharge port and the hydraulically operated device;

the piston separating a hydraulic chamber formed between the piston and the discharge end and a gas expansion chamber formed between the piston and the power end, the hydraulic fluid disposed in the hydraulic chamber;

the exhausting the first volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the first gas generator being communicated into the gas expansion chamber; and

the exhausting the second volume of pressurized hydraulic fluid comprises driving the piston toward the discharge end in response to a gas produced by the igniting the second gas generator being communicated into the gas expansion chamber.

20. The method of claim **19**, wherein the hydraulically operated device is connected in a well system.

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